National Park Service
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Natural Resource Program Center

Understanding the Science of Climate Change

Talking Points – Impacts to Alaska Boreal and Arctic

Natural Resource Report NPS/NRPC/NRR—2010/???

ON THE COVER

An autumn susnet over the bunkhouse at Serpentine Hot Springs, Bering Land Bridge National Preserve; NPS photo.

Understanding the Science of Climate Change

Talking Points – Impacts to Alaska Boreal and Arctic

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Caroline Jezierski
Kenai Fjords National Park
500 Adams Street, Suite 103
Seward, AK 99664-1727

Amanda Schramm
National Park Service Pacific West Region
909 First Avenue
Seattle, WA 98104

Rachel Loehman
Rocky Mountain Research Station
Fire Sciences Laboratory
5775 West US Hwy 10
Missoula, MT 59808-9361

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Contents

I. Introduction

Purpose

Climate change presents significant risks to our nation's natural and cultural resources. Although climate change was once believed to be a future problem, there is now unequivocal scientific evidence that our planet's climate system is warming (IPCC 2007a). While many people understand that human emissions of greenhouse gases have contributed to recent observed climate changes, fewer are aware of the specific impacts these changes will bring. This document is part of a series of bioregional summaries that provide key scientific findings about climate change and impacts to protected areas. The information is intended to provide a basic understanding of the science of climate change, known and expected impacts to resources and visitor experience, and actions that can be taken to mitigate and adapt to change. The statements may be used to communicate with managers, frame interpretive programs, and answer general questions to the public and the media. They also provide helpful information to consider in developing sustainability strategies and long-term management plans.

Audience

The Talking Points documents are primarily intended to provide park and refuge area managers and staff with accessible, up-to-date information about climate change and climate change impacts to the resources they protect.

Organizational Structure

Following the Introduction are three major sections of the document: a Regional Section that provides information on changes to Alaska Boreal and Artic, a section outlining No Regrets Actions that can be taken now to mitigate and adapt to climate changes, and a general section on Global Climate Change. The Regional Section is organized around seven types of changes or impacts, while the Global Section is arranged around four topics.

Regional Section

- Temperature
- The Water Cycle (including snow, ice, lake levels, sea levels and sea level rise, and ocean acidification)
- Vegetation (plant cover, species range shifts, and phenology)
- Wildlife (aquatic, marine, and terrestrial animals, range shifts, invasive species, migration, and phenology)
- Disturbance (including range shifts, plant cover, plant pests and pathogens, fire, flooding, and erosion)
- Cultural Resources
- Visitor Experience

Global Section

- Temperature and Greenhouse Gases
- Water, Snow, and Ice
- Vegetation and Wildlife
- Disturbance

Information contained in this document is derived from the published results of a range of scientific research including historical data, empirical (observed) evidence, and model projections (which may use observed or theoretical relationships). While all of the statements are informed by science, not all statements carry the same level of confidence or scientific certainty. Identifying uncertainty is an important part of science but can be a major source of confusion for decision makers and the public. In the strictest sense, all scientific results carry some level of uncertainty because the scientific method can only "prove" a hypothesis to be false. However, in a practical world, society routinely elects to make choices and select options for actions that carry an array of uncertain outcomes.

The statements in this document have been organized to help managers and their staffs differentiate among current levels of uncertainty in climate change science. In doing so, the document aims to be consistent with the language and approach taken in the Fourth Assessment on Climate Change reports by the Intergovernmental Panel on Climate Change (IPCC). However, this document discriminates among only three different levels of uncertainty and does not attempt to ascribe a specific probability to any particular level. These are qualitative rather than quantitative categories, ranked from greatest to least certainty, and are based on the following:

- "What scientists know" are statements based on measurable data and historical records. These are statements for which scientists generally have high confidence and agreement because they are based on actual measurements and observations. Events under this category have already happened or are very likely to happen in the future.

- "What scientists think is likely" represents statements beyond simple facts; these are derived from some level of reasoning or critical thinking. They result from projected trends, well tested climate or ecosystem models, or empirically observed relationships (statistical comparisons using existing data).

- "What scientists think is possible" are statements that use a higher degree of inference or deduction than the previous categories. These are based on research about processes that are less well understood, often involving dynamic interactions among climate and complex ecosystems. However, in some cases, these statements represent potential future conditions of greatest concern, because they may carry the greatest risk to protected area resources.

II. Climate Change Impacts to Alaska Boreal and Arctic

The Boreal and Arctic Bioregion that is discussed in this section is shown in the map to the right. A list of parks and refuges for which this analysis is most useful is included on the next page. To help the reader navigate this section, each category is designated by color-coded tabs on the outside edge of the document.

Summary

Alaska is a huge state spanning 375 million acres and occupying nearly one-fifth of the land area for the contiguous 48 states. More than half of the coastline of the entire United States is in Alaska. Due to the great size and geographically diverse nature of Alaska, two bioregional documents were produced: “Boreal and Arctic” and “Alaska Maritime and Transitional.” In Alaska, the vast majority of the land is public; with approximately 222 million acres (approximately 60%) designated federal lands and another 90 million acres (approximately 24%) in state ownership. There are 17 National Park Service (NPS) areas in Alaska covering over 54 million acres; this represents two-thirds of the land in the entire National Park system. Wrangell-St. Elias is the largest NPS unit at over 13 million acres in size. There are 16 National Wildlife Refuges in Alaska totaling over 76 million acres, representing approximately 80% of the entire National Wildlife Refuge system. The two national forests in Alaska encompass nearly 22 million acres; Tongass National Forest is the largest United States Forest Service unit, with nearly 17 million acres. The Bureau of Land Management manages almost 78 million acres in Alaska.

Summary Continued

Increased mean, minimum, and maximum annual and seasonal temperatures, especially in the spring and winter, are expected to result in earlier spring budding and lengthening of the growing season. The number of snow-free and frost-free days are increasing, while glaciers and sea ice extent are decreasing. Drought stress in the boreal forest from drier summers is leading to reduced tree growth, reduced carbon sequestration, and increased disturbance from fires and insect outbreaks. This increased disturbance may lead to shifts in vegetation and wildlife. In the Arctic, shrub expansion into the tundra is altering the forage availability for caribou and other wildlife. Sea surface temperature increases and loss of sea ice are causing shifts in plankton availability in the Bering Sea, which in turn is changing the distribution and population dynamics of fish, seabird, and wildlife species. Loss of sea ice in the Arctic Ocean will change the terrestrial, oceanic, and human ecosystems. Thawing permafrost lead to damaged infrastructure; altered soil conditions; and shifts in water and plant communities, which may, in turn, affect animal communities and alter fire regimes. Changes in terrestrial and marine wildlife distributions may affect visitor experiences and complicate subsistence hunting throughout the region. It is important to note that climate changes that may occur in the Boreal and Arctic bioregion include large-scale effects that are likely to impact many areas similarly, but also localized effects that may differ in individual locations based on the natural conditions of the area (landforms, precipitation patterns, abundance of ice or water, presence of permafrost).

List of Parks and Refuges

U.S. National Park Service Units

- Bering Land Bridge NPR
- Cape Krusenstern NM
- Denali NP & NPR
- Gates of the Arctic NP & NPR
- Inupiat Heritage Center
- Kobuk Valley NP
- Noatak NPR
- Wrangell-St. Elias NP & NPR
- Yukon - Charley Rivers NPR

U.S. Fish & Wildlife Service Units

- Arctic NWR
- Innoko NWR
- Kanuti NWR
- Koyakuk NWR
- Nowitna NWR
- Selawik NWR
- Tetlin NWR
- Togiak NWR
- Yukon Delta NWR
- Yukon Flats NWR

Acronym	Unit Type
NM	National Monument
NP	National Park
NPR	National Preserve
NWR	National Wildlife Refuge

A. TEMPERATURE

What scientists know….

- Mean annual temperatures in Alaska increased an average 1.7°C (3.1°F) over the last six decades. The period from 1949 to 1975 was colder than the period from 1977 to 2008. A large increase in temperature was observed in 1976 coinciding with a shift in the Pacific Decadal Oscillation; there has been little additional warming since 1977 for most of Alaska (Alaska Climate Research Center 2009).

- For the state of the Alaska, there has been a general warming rate of 0.16 to 0.37°C (0.29 to 0.67 °F) per decade from 1951 to 2001(Hartmann and Wendler 2005).

- Alaska-wide minimum temperatures have warmed proportionally more than mean or maximum temperatures; the lowest (coolest) temperatures have warmed more than the highest (hottest) temperatures. Over the past four decades, minimum temperatures have increased particularly during the winter and spring with less substantial changes or decreases in autumn (Stafford et al. 2000; Alaska Climate Research Center, Geophysical Institute 2009). Average minimum temperatures increased per decade 0.23°C (0.41°F) during the summer and 0.35°C (0.63 °F) during the winter (Keyser et al. 2000). Spring minimum temperatures increased an average of 0.47°C (0.85°F) per decade; Alaskan stations recorded increases greater in magnitude and significance (all $p < 0.05$) than recorded at Canadian stations (Keyser et al. 2000).

- Maximum temperature increases were observed throughout Alaska; the greatest increases were observed during the spring with an average increase of 0.46°C (0.83°F) per decade (Keyser et al. 2000). Average maximum temperatures increased per decade 0.14°C (0.25°F) in the summer and 0.24°C (0.43°F) in the winter (Keyser et al. 2000).

- From 1949 to 2009, the regional mean annual temperatures for the Arctic, Interior, and West Coast of Alaska increased between 1.4 to 2.5°C (2.5 to 4.5°F) and the greatest change in mean seasonal temperatures (2.3 to 4.9°C, 4.1 to 8.8°F) were observed in the winter (Alaska Climate Research Center 2010).

- Fairbanks experienced a general warming trend from 1906 to 2006. The mean annual temperature increased 1.4°C (2.5°F) compared to 0.8°C (1.44°F) worldwide. Temperatures increased during the winter, spring, and summer seasons, while autumn showed a slight decrease in temperature. The number of days with very low temperatures (less than -40°C) has decreased, on average, from 14 to 8 days annually (Wendler and Shulski 2009).

- An increase in the growing season in Fairbanks was observed from 1906 to 2006. For the 0°C (32°F) freezing point, the growing period increased from 85 to 123 days (45%). At -2.2°C (28°F), the temperature threshold for frost-resistant plants, the growing season increased from 113 to 144 days, or 27% (Wendler and Shulski 2009).

This climate station in Denali National Park is used to monitor temperature and other climatic factors; NPS photo.

Comparison photos of Teklanika Glacier in Denali National Park show glacial retreat.; NPS photo.

- Spring break-up on the Tanana River has advanced by 0.71 days per decade coinciding with increases in spring surface temperature in interior Alaska (80+ years of data) (Keyser et al. 2000).

- The mean diurnal temperature ranges (difference between maximum and minimum temperatures) decreased 0.3°C (0.5°F) between 1949 and 1998. For this region, the winter mean diurnal temperature ranges decreased by 0.6 to 0.9°C (1.1 to 1.6°F), but both summer and autumn showed slight increases in mean diurnal temperature ranges (Stafford et al. 2000).

- There has been a warming trend in the Arctic over the past 400 years (Overpeck et al. 1997).

- From 1982 to 2008, summer tundra land temperatures measured by the summer warmth index (sum of the monthly mean temperatures that are above freezing) increased 24% for the northern hemisphere as a whole; the North America Arctic tundra experienced a 30% increase in summer land temperatures (Walker et al. 2009).

- Since the mid-1960s, the melt date (date of final snowmelt) in northern Alaska has advanced by about 8 days (Stone et al. 2002).

- The majority of Alaskans polled anticipate that global climate change will result in more comfortable temperatures (Leiserowitz and Craciun 2006).

What scientists think is likely….

- As temperatures increase in the Arctic, the sea ice extent decreases. Reduced sea ice extent will have an effect on land temperature, potentially extending up to 1,500 km (930 miles) inland; higher temperatures on land will contribute to more rapid permafrost thawing (Lawrence et al. 2008).

- In the Arctic, warmer temperatures in spring are projected to lead to earlier sea ice break-up and warmer temperatures in the fall could lead to sea ice development delays (Comiso 2003; Overland et al. 2002).

- Modeling predicts that the mean number of frost days for the Boreal and Arctic bioregion will decrease between 20 and 40 days by the end of the century compared to trends from 1961 to 1990 (Meehl et al. 2004).

- Mid-range emission simulations (A1B) predict that by 2091, the average monthly temperatures for Barrow, where the Inupiat Heritage Center is located, will increase by 1.1 to 2.8°C (5.0°F) during the summer months and 8.9 to 14.6°C (16.0 to 26.0°F) during the winter months (Scenarios Network for Alaska Planning 2009a).

- According to mid-range emission simulations (A1B), temperatures in Kotzebue, the closest large community to the Western Arctic National Parklands, will increase 3 to 5 times more in the winter than in the summer by the year 2091. Two months that historically had average temperatures below freezing will increase to above freezing by 2061 (Scenarios Network for Alaska Planning 2009b).

What scientists think is possible….

- Temperatures are predicted to increase at an average rate of 0.56°C (1.0°F) per decade for National Park units and Yukon Flats National Wildlife Refuge (Loya and Rupp 2009a, b, c, d, e, f, g, h).

- Average winter temperatures for the national park units are predicted to increase by 5.6 to 7.8°C (10.1 to 14.0°F) by 2080 (Rupp and Loya 2009a, b, c, d, e, f, g, h).

- Modeling indicates that average annual temperatures in Bering Land Bridge National Preserve, Denali National Park and Preserve, Yukon-Charley Rivers National Preserve, and Yukon Flats National Wildlife Refuge are predicted to shift from below freezing to above freezing during the 21st century (Loya and Rupp 2009, Rupp and Loya 2009a, b, h).

- By the end of the century, the growing season in Yukon Flats National Wildlife Refuge could be 1 month longer than it is currently (Loya and Rupp 2009).

B. THE WATER CYCLE

What scientists know….

- Glaciers throughout Alaska are retreating and/or thinning. The number of glaciers in Alaska is estimated to be more than 100,000 including tidewater glaciers; many of these glaciers have been melting since the mid 19th century (Molnia 2008). All glaciers below ~1500 m (4,905ft) are melting and over 98% of glaciers examined are retreating and/or thinning (Molnia 2007).

Sea ice in the Beaufort Sea, in the Arctic Refuge coastal plain, and the Brooks Range Mountains in the background; USFWS photo.

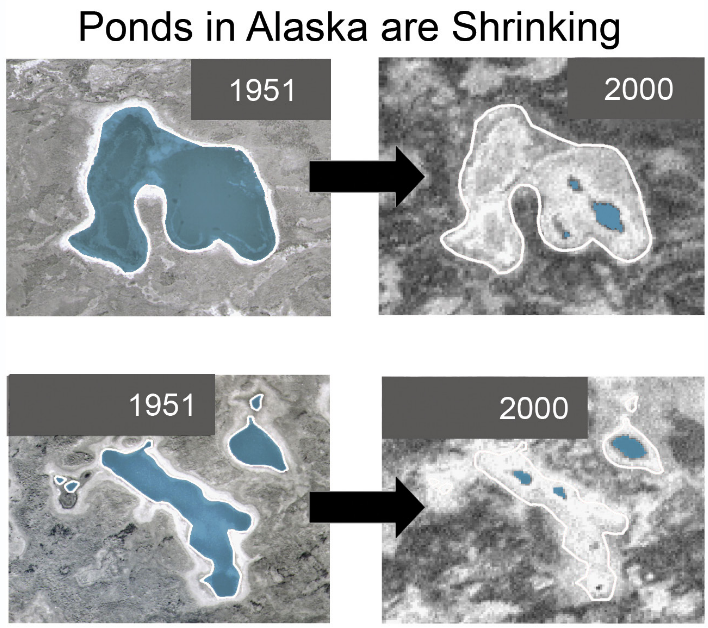
- The melting rate of glaciers throughout Alaska has increased in recent decades as has their contribution to sea level rise (Dyurgerov and Meier 2000; Larsen et al. 2007a). From the mid 1990s to the early 2000s, the rate of glacial thinning in Alaska tripled compared to the mid 1950s to mid-1970s time period; the loss of ice during this period was equivalent to nearly twice the estimated annual loss of ice from the Greenland Ice Sheet. Over the last half of the 20th century, Alaska glaciers contributed the largest single measured glaciological contribution to sea level, with a total annual volume change of –52 ± 15 km3/year (12.3 ± 3.6 miles3) water equivalent, which equates to a rise in sea level of 0.14 (0.04 mm/year, or 0.002 in/year). (Arendt et al. 2002).

- In Denali National Park and Preserve many of the glaciers are retreating an average of 66 ft per year (Adema et al. 2007).

- Changes in sea ice in both the Arctic Ocean and the Bering Sea have been observed. Ice cover on the Bering Sea shelf decreased significantly from 1954 to 2006 (Mueter and Litzow 2008). There is a net thinning of the Arctic sea ice (~0.6 m, or 1.97 feet, between 2004 and 2008) and a decrease in the perennial ice that remains. The amount of summer sea ice remaining, or the summer sea ice minimum, is decreasing; the 2009 summer minimum was the third-lowest recorded since 1979 (Perovich et al. 2009).

- The Arctic Ocean sea ice melt season has increased 6.4 days per decade between 1979 and 2007 (Hansen 2010).

- Snow patterns in northern Alaska, measured at Barrow, have changed in the past five decades. From 1972 to 2000, the duration of the snow-free period increased by 3 to 6 days per decade and the first week in spring without snow cover shifted to 3 to 5 days earlier per decade (Dye 2002). In addition to the frequency, the mean intensity of precipitation has decreased in the Arctic since 1972 (Curtis et al. 1998) and around



Riordan *et al.*[514]

Ponds across Alaska, including those shown above in the northeastern interior of the state, have shrunk as a result of increased evaporation and permafrost thawing. The pond in the top pair of images shrunk from 180 to 10 acres; the larger pond in the bottom pair of images shrunk from 90 to 4 acres.

Aerial photos show ponds shrinking over time due to increased evaporation and permafrost thawing. Copyright Riordan et al.

Barrow, the melt date has advanced by 8 days since the mid-1960s (Stone et al. 2002).

- Observed decreases in snow extent reduce the albedo or the proportion, or percentage of solar radiation of all wavelengths reflected by a surface (Richter-Menge and Overland 2009). With a reduction in the albedo of northern Alaska, both from reduction of snow and loss of sea ice, more of the sun's energy will be absorbed rather than reflected creating a positive feedback loop of increasing temperatures that leads to more ice melt, a delay in fall ice formation, and reduced sea ice volume (Francis et al. 2009).

- In western and interior Alaska, the mean annual precipitation increased by 7 to 9% between 1949 and 1998. Precipitation in western Alaska increased by 25% in winter, 21% in autumn, and 17% in spring; summer precipitation decreased by 11%. In the interior, autumn precipitation increased by 19%, with slight increases during the other seasons (Stafford et al. 2000).

- In the Arctic, the mean annual and seasonal precipitation decreased significantly between 1949 and 1998. Annual precipitation decreased by 36%, with the greatest decrease observed in the winter (106%) and the least decrease in the summer (16%) (Stafford et al. 2000).

- Warmer temperature and altered precipitation patterns are leading to an increase in the average annual discharge of fresh water from rivers to the Arctic Ocean, which contributes to sea level rise. A 7% increase in discharge was observed from 1936 to 1999 for the six largest Eurasian rivers (Peterson et al. 2002). From 2000–2007, a 10% increase was observed in the rate of fresh water discharge compared to 1936 to 1999 averages. Similarly, a 6% increase in the mean discharge was observed in North American Arctic rivers from 2000 to 2007 compared to the mean between 1973 and 1999 (Shiklomanov 2009).

- From the 1950s to 2000s, closed-basin ponds in boreal regions decreased in area and number; the area of subarctic ponds decreased by 4 to 31%, whereas Arctic ponds did not show a marked change in pond area (Riordan et al. 2006). During the same time period near Council, Alaska, 22 out of 24 ponds being studied decreased in area (Yoshikawa and Hinzman 2003).

- In 2004, a retrogressive thaw slump (slope failure resulting from thawing permafrost) occurred on the upper Selawik River in the Selawik National Wildlife Refuge as a result of thawing permafrost. The Selawik Slump is the largest of its kind in North America and is increasing in size and projected to increase for decades. It covers an area of 8.7 acres and as of 2009 has deposited approximately 12.6 million ft3 of sediment into the Selawik river (Crosby 2009).

- Arctic wetland emissions of methane, a powerful greenhouse gas, increased by 31% between 2003 and 2007 due to temperature increases (Bloom et al. 2010).

- As permafrost thaws, thermokarst features, such as ponds, form. The thawing also results in an increase in surface water storage and runoff, increased albedo, and an increase in the depth of the active layer of the permafrost (soil overlaying the permafrost that experiences seasonal thawing and freezing) (Francis et al. 2009).

What scientists think is likely….

- Acidification of Alaska's oceans is occurring at a faster rate than in tropical waters. Cold water, shallow continental shelves, and high productivity of Alaska's marine waters facilitate the increased absorption of CO_2, reduced deep water circulation, and decomposition, respectively; all contribute to increased acidification compared to other regions (University of Alaska Fairbanks 2009).

- Models predict that precipitation will increase in all national park units in this bioregion from 12 to 33% in the summers and 25 to 65% in the winter. Due to increased evapotranspiration (the transport of water into the atmosphere from surfaces, including soils and vegetation) from temperature increases and lengthened growing seasons, the summers and falls will actually be drier than they are currently (Rupp and Loya 2009a, b, c, d, e, f, g, h).

- Yukon Flats National Wildlife Refuge is predicted to have drier summers and falls. By 2035, it is predicted to be 10% drier; by 2075, 25% drier (Loya and Rupp 2009).

- Evidence from studies conducted in southeast Alaska indicate that as watersheds become deglaciated and plant succession occurs, the input of organic carbon and inorganic nitrogen into the streams will be altered thereby changing the land-to-ocean fluxes of nutrients (Hood and Durelle 2008).

- Glaciers respond to climate with a one-year lag time. Therefore, annual changes in the volume of glaciers will follow the changes in weather. With the predicted increase in temperatures, it can be predicted that glaciers will respond by melting (Dyurgerov and Meier 2000).

- With the loss of sea ice, there will be an increase in surface air temperature and clouds, which increase longwave radiation even while they block incoming solar radiation, resulting in increased net radiation that contributes to further decrease in sea ice extent (a positive feedback loop). Water vapor will most likely increase, resulting in increased precipitation (Francis et al. 2009).

- Modeling results predict an overall decrease in frost days (days with a nighttime temperature below 0°C) by the end of the 21st century, with the most significant changes in the northwest U.S. (Meehl et al. 2004).

Ruth Glacier at Denali National Park; NPS photo.

What scientists think is possible….

- The North Atlantic Deep Water (NADW) formation, moderates cold weather and relies on cold, heavy salt water for its circulation. Average annual freshwater discharge into the Arctic Ocean increased 7% between 1936 and 1999 in correlation with changes in both the North Atlantic Oscillation and global mean surface air temperature. If freshwater discharge into the Arctic continues to increase and enter the northern Atlantic Ocean, by 2100 the amount of discharge would be approaching the point in which the NADW may not be sustained. (Peterson et al. 2002).

- Sea level is predicted to rise an additional 7 to 23 inches by the end of the 21st Century due to thermal expansion, fresh water input and wind-driven effects (IPCC 2007b).

- Recent projections of the contribution of glaciers and ice caps to sea level rise are higher than previously believed. Glaciers and ice caps may exceed or equal the contribution of the Greenland and Antarctic ice sheets to sea level rise throughout the next century; the volume of the glaciers and ice caps will be decreased less than 35%, leaving substantial volume left to melt (Meier et al. 2007).

Aspen production, as well as fruit and vegetable production has increased with the longer growing season. An aspen forest in Yukon Flats National Wildlife Refuge (top); wild berries in Innoko National Wildlife Refuge (bottom). USFWS photos.

C. VEGETATION

What scientists know….

- Based on a meta analysis of studies looking at phenological shifts (shifts in life cycle processes), species at higher latitudes are reacting more strongly to the more intense change of temperatures at higher latitudes compared to lower latitudes (Root et al. 2003).

- Climate has demonstrably affected terrestrial ecosystems through changes in the seasonal timing of life-cycle events (phenology), plant growth responses (primary production), and biogeographic distribution (Parmesan 2006; Field 2007). Statistically significant shifts in Northern Hemisphere vegetation phenology, productivity, and distribution have been observed and are attributed to 20th century climate changes (Walther 2002; Parmesan and Yohe 2003; Parmesan 2006).

- Between 1980 and 2000, vegetation responses mainly to changes in temperature resulted in an observed trend toward earlier spring budburst and increased maximum leaf area at high northern latitudes (Lucht et al. 2002). In the Arctic, there is evidence of earlier greening and later plant senescence (seasonal dying off) (Griffith et al. 2001) and an increasing greening trend was observed during the 1990s (Stow et al. 2003).

- Based on over 40 years of data collected across Alaska, the growing season has lengthened by an average of 2.6 days per 10 years (Keyser et al. 2000). Variations in the start of the growing season were 5.6 days earlier between 1982 and 1991, 3.9 days later between 1991 and 1992 (attributed to the eruption of Mount Pinatubo), and 1.7 days earlier between 1992 and 1999 (Tucker et al. 2001). On average, an advance in average leaf onset date of 1.10 days per 10 years was observed between the 1950s and 1990s (Keyser et al. 2000).

- Increases in temperature and CO_2 between the 1980s and the 2000s resulted in increased photosynthetic activity or growth on tundra: 7% on Arctic tundra, 11% on North American tundra (Goetz et al. 2005; Walker et al. 2009), and 17% across the bioregion (Jia et al. 2003).

- Net primary production for both aspen (Populus tremuloides) and white spruce (Picea glauca) stands in Alaska and northwestern Canada increased by 20% with the advance in the start of the growing season (Keyser et al. 2000).

- Interior forests did not exhibit expected increases in photosynthetic activity, or intensity or length of growing season with increasing temperatures from 1981 to 2003 (Goetz et al. 2005). The tree-ring records indicate that radial growth has decreased with increasing temperature due to temperature-induced drought stress in white spruce (Barber et al. 2000).

- Tree growth, measured from tree-ring chronologies, increased from 1900–1950 at almost all sites at and near alpine and arctic treelines; significant declines in tree growth were common after 1950 in all but the Alaska Range sites and declines were most common in the warmer and drier sites at or near alpine and arctic treeline (Lloyd and Fastie 2002).

- Based on tree-ring chronologies, it is evident that forest expansions into the tundra have coincided with increased temperatures. In Noatak National Preserve, forest expansion into the tundra has been occurring over the past 150 years (Suarez et al. 1999). On the Seward Peninsula, chronologies indicate spruce have successfully established progressively farther from the forest limit in the upland tundra since the 1880s and in the lowland sites since 1920 (Lloyd et al. 2003).

- Based on current and historic photographs from the Arctic, a widespread increase in shrub abundance, primarily along hillsides and valleys, has occurred from the 1940s to 2000s (Sturm et al. 2001; Tape et al. 2006).

What scientists think is likely….

- Land use changes in the boreal region may result in greater soil carbon losses than in other areas. If forests are converted to agricultural land, the resulting carbon losses could induce a positive feedback to climatic warming (Grünzweig et al. 2004).

- In the Arctic, shrub abundance leads to deeper snow, which promotes higher winter soil temperatures, greater microbial activity, and more plant-available nitrogen. High levels of soil nitrogen favor shrub growth the following summer. Continued air temperature warming could result in large areas of tundra being converted to shrubland due to this positive feedback cycle (Sturm et al. 2005).

- Drought stress in the boreal forests limits carbon uptake. If this trend continues, the carbon sequestration capacity of these forests may be lower than currently expected (Barber et al. 2000).

- Modeling exercises indicate that boreal tree ecotones have varying responses to warming and therefore treeline advancement will vary spatially and temporally (Lloyd et al. 2003).

- During nine years of experimental climate change manipulations on tundra vegetation, there was a loss of 30 to 50% of the plant species; evergreen shrubs and understory forbs (rarer species) declined more strongly than other species or disappeared completely (Chapin et al. 1995). A "greenhouse climate" simulation also indicates a reduction in the areas occupied by forbs, lichens, and mosses, a northward shift of shrubs and forested areas, particularly evergreen forests (Kaplan et al. 2003).

- As snow cover decreases, sunlight will be available to plants earlier than in the past (Dye 2002).

What scientists think is possible….

- As shrub abundance increases and encroaches onto tundra, the newly modified landscape may become a carbon sink (absorb, rather than emit, carbon) (Sturm et al. 2001).

- As warming continues, growth rates in boreal trees will decrease. Growth rates in multiple species have been observed in tandem with increased temperatures. All members of the genus Picea except P. sitchensis, and Pinus banksiana exhibited stronger-than-expected declines with warmer temperatures, likely due to conditions such as direct temperature stress, temperature-mediated drought stress, and in some cases pollution. (Lloyd and Bunn 2007).

- Treelines will advance into areas currently occupied by Arctic tundra, altering ecosystem nutrient availability (Burkett et al. 2005).

- A variety of future climate scenarios for vegetation distribution in interior Alaska show Black spruce as the dominant vegetation type. A scenario of warming coupled with increasing fire interval resulted in the greatest expansion of Black spruce (Calef et al. 2005).

- A model of the impact of climate warming on Arctic plant communities showed dif-

A cottongrass field in Gates of the Arctic. Cottongrass is an important food source for arctic snow geese; NPS photo.

ference responses in the short term (couple years), longer term (50 to 75 years) and 200 years. After 200 years, the vegetation was not typical of vegetation today. The model showed an increase in lichen, decrease in sedges, increases in deciduous and evergreen shrubs (Epstein et al. 2000).

- Models indicate that vegetation is an important driver for permafrost and its seasonally-thawed active soil layer and affects soil moisture (Francis et al. 2009).

- By 2050, models predict that warmer, drier conditions and associated increased fire will alter the vegetation composition of Yukon Flats National Wildlife Refuge and similar lands. A shift to earlier successional plant communities was predicted, with deciduous forests replacing white and black spruce forests which could experience a 50% decline and the percentage of mature forest will decrease substantially (Loya and Rupp 2009).

A Bluethroat Thrush perched in the Yukon Delta National Wildlife Refuge. Over 300 bird species in Alaska shifted their population centers between 1966 and 2004. USFWS photo.

D. WILDLIFE

What scientists know….

- A meta-analysis of climate change effects on range boundaries in Northern Hemisphere species of birds, butterflies, and alpine herbs shows an average shift of 6.1 kilometers (3.8 miles) per decade northward (or meters per decade upward), and a mean shift toward earlier onset of spring events (frog breeding, bird nesting, first flowering, tree budburst, and arrival of migrant butterflies and birds) of 2.3 days per decade (Parmesan and Yohe 2003).

Historically, about 10% of the Pacific Brant population wintered in Alaska. The number is now closer to 30%, and corresponds with warming temperatures. USGS photo.

- An increase in Porcupine caribou calf survival observed from 1985 to 1996 can be attributed to increased temperatures which led to more forage available to females during calving and lactation (Griffith et al. 2001; Griffith et al. 2002).

- The body size of masked shrews in Alaska increased significantly during the second half of the twentieth century. Evidence indicates that warmer winter weather conditions increased the survival rate of shrew's prey, providing greater food availability for the shrew (Yom-Tov and Yom-Tov 2005).

- Thirty percent of the Pacific Brant population now spends their winters in Alaska instead of migrating south to Mexico. In the past, only 10% wintered in Alaska. Climate warming corresponds with the shift in migration patterns (Ward et al. 2009).

- On the Yukon-Kuskokwim Delta, hatch dates for geese and spectacled eiders have advanced. Young are hatching 5 to 10 days earlier than they did 25 years ago. May temperatures, timing of river ice breakup, and date when the tundra became snow-free correlated with hatch dates (Fischer et al. 2009).

- Both common and thick-billed murres showed population reductions with large sea surface temperature shifts in either direction (Irons et al. 2008), but productivity was found to be greater when summer sea surface temperatures were colder (Byrd et al. 2008).

- On the Pribilof Islands in the Bering Sea, red-legged and black-legged kittiwakes, small seabirds in the gull family, bred earlier and hatch dates progressed by 0.58 to 0.88 days per year between 1975 and 2006. For both species of kittiwakes nesting in the Pribilofs, productivity appears to be higher when nesting begins earlier, when ice is abundant near foraging grounds, and in winter and spring when sea surface temperature cool. For murres, productivity is higher during cooler summers. (Byrd et al. 2008).

- The Audubon Christmas Bird count, a citizen science project, has documented

Nearly all threatened spectacled eiders spend the winter in a small area of ocean and sea ice south of St. Lawrence Island in the Bering Sea. This picture shows tens of thousands of spectacled eiders roosting in an open lead of the ice pack. USFWS photo.

that the center of the mean annual latitudinal center of abundance for over 300 bird species has shifted nearly 40 miles (64.4 km) between 1966 and 2004. There is a significant correlation between temperature trends and shifts in the center of abundance. The mean latitudinal shift for the pine siskin, a small finch and year-round resident of southern Alaska, was approximately 288 miles (463.7km) north (Niven and Butcher 2009).

- The timing of the plankton bloom in the Bering Sea is associated with the sea ice edge. Late seasonal ice retreat supports benthic organisms. When there is no ice, or early ice retreat, a mostly pelagic ecosystem is supported (Hunt and Stabeno 2002; Hunt et al. 2002; Overland and Stabeno 2004). An increase in air and ocean temperatures, a reduction in sea ice, reduction benthic prey populations, and an increase in pelagic fish resulted in a shift in marine mammal population distributions (Grebmeier et al. 2006).

- From 1982 to 2006, fish and invertebrate species shifted north on an average of 34 ± 56 km (21 ± 35 miles) in response to the shift in the cold water pool on the Bering Sea shelf. A reorganization of community composition was also observed (Mueter and Litzow 2008).

What scientists think is likely….

- Changes to the terrestrial and aquatic species compositions in parks and refuges are likely to occur as ranges shift, contract, or expand. Rare species and/or communities may become further at risk, and additional species could become rare (Burns et al. 2003).

- Parks and refuges may not be able to meet their mandate of protecting current species within their boundaries, or in the case of some refuges, the species for whose habitat protection they were designed. While wildlife may be able to move northward or to higher elevations to escape some effects of climate change, federal boundaries are static (Burns et al. 2003).

- Modeling suggests that the distribution of the little brown bat will expand northward in Alaska in the next century (Humphries et al. 2002).

- Of the 83 species of Arctic and Alpine birds, 72% are considered moderately or highly vulnerable to the impacts of climate change, primarily due to their long-distance migrations and their reliance on arctic and alpine habitats that are vulnerable to effects of climate change (NABCI 2010).

- As trees and shrubs encroach on areas currently occupied by tundra, Arctic and alpine breeding birds' breeding habitats will be reduced or eliminated (NABCI 2010).

- Coastal seabirds such as the arctic Ivory Gull, Aleutian Tern, and Kittlitz's Murrelet show medium or high vulnerability to climate change due to their low reproductive potential and their reliance on marine food webs that are also threatened by climate change (NABCI 2010).

- Kittlitz's murrelets are closely associated with glaciated fjords and coastlines. With glacial retreat, important habitats will be lost and Kittlitz's populations may decline (USFWS 2006).

- Thawing permafrost may result in changes to the distribution and abundance of waterfowl, shorebirds, and gulls due to shifts in surface water and plant communities; contaminants such as mercury and organic pollutants may also be released into the aquatic environment as the permafrost thaws, increasing contaminant exposure for birds that rely on the marine ecosystem for food (NABCI 2010).

- Boreal forest birds will expand into the arctic as climate changes, causing new avian communities to develop (NABCI 2010).

- Arctic marine mammals that are closely linked to sea ice, such as the narwhal and polar bear, are predicted to be the most sensitive to climate change (Laidre et al. 2008).

- As sea surface temperatures change, the distribution of plankton and forage fish will change and as a result, seabirds and marine mammal forage patterns, distribution, and population dynamics change (Hunt et al. 2002; Irons et al. 2008, Meehan et al. 1999).

- In the northern Chukchi Sea and in the Canada Basin of the Arctic Ocean, an undersaturation of aragonite (reduction in levels of aragonite, a mineral essential for developing the shells or calcium-carbonate skeletons of some marine fauna) has occurred due to ocean acidification and freshwater influx from sea ice melting (Bates et al. 2009; Yamamoto-Kawai et al. 2009). Models show that high latitude ocean waters could be undersaturated with magnesium-calcite minerals of higher solubility than aragonite in less than a few decades due to ocean acidification (Andersson et al. 2008). Undersaturation can affect planktonic and benthic calcifying (shell building) fauna (e.g., bivalves and echinoderms), food sources of large benthic feeding mammals such as walrus and gray whales, planktivourous birds, and potentially the composition of the ecosystem (Bates et al. 2009). Ocean acidification is likely more rapid and severe in Alaska than in tropical waters, and will make shell building more difficult for pteropods, oysters, crabs and other shelled marine animals. It will also impact growth, reproduction, and survival of many marine organisms, including pteropods, which make up nearly half of the pink salmon's diet (University of Alaska Fairbanks 2009).

- Changes in marine community organization in the Bering Sea caused by warming climate and associated loss of sea ice will alter availability of snow crab and other fisheries resources (Mueter and Litzow 2008)

What scientists think is possible….

- Changing vegetation cover in many park areas will affect wildlife species dependent on those habitats. Animals will eventually

A bearded seal hauls out on sea ice. Sea ice in the Arctic is rapidly decreasing due to warmer temperatures (top); Ocean acidification will affect the food sources of marine mammals like walruses (bottom); USFWS photos.

The birthing season for moose is closely linked to climatic trends that provide the most hospitable conditions for bearing and rearing young; climate change may hinder moose calf survival by throwing this relationship out of sync. NPS Photo.

occupy landscapes vacated by glacial ice, and utilize new alpine lakes after ice is gone (Burkett et al. 2005).

- The synergism of rapid temperature rise and stresses such as habitat destruction may disrupt connectivity among species, lead to reformulation of species communities, and result in numerous extirpations and/or extinctions (Root et al. 2003).

- The population cycles of birds and their prey, such as spruce budworm, will be decoupled in some Boreal areas due to warming temperatures (Burkett et al. 2005; Juday et al. 2004). Warming trends have coincided with increases in spruce budworm in Alaska in recent years and suggest that populations could continue to move northward with continued climate warming (Juday 1998; Juday et al. 2004).

- Earlier onset of spring will affect productivity of nesting shorebirds based on whether they are able to change their migration and nesting schedules to coincide with the time when the most insects are available (NABCI 2010).

- Changes in weather and tundra habitats could decrease the abundance of lemmings, which could in turn reduce the numbers of their predators, or cause the predators to prey on other birds and their eggs (NABCI 2010).

- Millions of geese could lose almost half of their breeding habitat due to a predicted change in vegetation in the Arctic from tundra to taiga and boreal forest (Zöckler and Lysenko 2001).

- Ice worm populations in Denali National Park and Preserve and the Alaska Range are in danger of local extinctions as glaciers melt due to climate change (Shain 2009).

- An analysis of potential climate change impacts on mammalian species in U.S. national parks indicates that with a doubling of atmospheric CO_2, about 8% of current mammalian species diversity may be lost on average. The greatest losses across all parks occurred in rodent species (44%), bats (22%), and carnivores (19%). Species are projected to decline in direct proportion to their current relative representation within parks. (Burns et al. 2003).

- The timing and synchrony of birth for moose in Denali National Park and Preserve are adaptations to long-term trends in climate that provide the most hospitable conditions to bear and rear young; climate change may decouple this relationship, hindering moose calf survival (Bowyer et al. 1998).

- In 2004, there were three instances of polar bear intraspecific predation and cannibalism in the Beaufort Sea. No other similar instances have been observed during more than 20 years of research. Researchers hypothesize that nutritional stresses related to the longer ice-free seasons may have led to the cannibalism incidents which could further reduce the population (Amstrup et al. 2006).

- The health of caribou and reindeer may be affected by changes in temperature and precipitation patterns. Warming could lead to an increase in insects and pests known to harass caribou. Changes in the freeze/thaw cycle may alter forage availability in late summer and winter which could decrease the carrying capacity of caribou and reindeer. Warmer and drier summers may reduce the availability of succulent forage for reindeer causing nutritional stress (Babcock et al. 1998).

- Changes in animal distributions may alter the interactions between animal commu-

Coastal erosion led to the collapse of this house in Shishmaref, a Native Alaskan community that was vacated due to increasingly severe coastal disturbances. NPS Photo.

nities. There is the potential that this may occur for native Alaska caribou and non-native reindeer (Babcock et al. 1998).

- A loss in tundra plant species diversity is predicted due to climate change. Wildlife species reliant upon diminishing plant species may be forced to shift to less suitable forage. For example, forbs that are selectively grazed upon by caribou during lactation or lichens used as over-wintering food by caribou (Chapin et al. 1995).

- Predicted shifts in forest community in Yukon Flats National Wildlife Refuge and similar habitats could result in less suitable habitat for caribou, but potentially increased habitat for moose (Loya and Rupp 2009).

- A retrogressive thaw slump on the upper Selawik River, Selawik National Wildlife Refuge, is above spawning habitat for sheefish (Inconnu), an important subsistence fish. Sediment input from the slump may reduce survival of eggs developing in the gravel. Other fish habitats in permafrost-dominated areas may be similarly threatened by thaw slumps and their associated sediment input into rivers (USFWS 2009).

- Fisheries (especially for pink salmon) may see a dramatic decrease if pteropods and other crustaceans, the salmons' prey, are negatively impacted by ocean acidification (University of Alaska Fairbanks 2009).

E. DISTURBANCE

What scientists know....

- Increase in coastal shoreline erosion rates were observed in the Arctic along parts of the Alaskan Beaufort Sea. Mean annual erosion rates increased from 6.8 meters (22.3 ft) per year (1955 to 1979), to 8.7 meters (28.5 ft) per year (1979 to 2002), to 13.6 meters (44.6 ft) per year (2002 to 2007). Different erosion rates were observed in different coastal ecosystems during the earlier years of the study, but erosion rates during the later years of the study were more uniform (Jones et al. 2009).

- Mean storm power value along the coast of the Arctic Ocean has increased 59% between the 1955 to 1979 time periods 2001 and 35% between the 1979 to 2001 and 2002 to 2006 time periods (Jones et al. 2009).

- In interior Alaska, the most extensive fires burn during unusually dry years. The frequency of unusually dry years increased from once or twice a decade in the 1950s to several times a decade at the end of the 20th century (Kasischke and Turetsky 2006).

- Shifts in the North American boreal region fire regime from the 1960s and 70s to the 1980s and 90s were characterized by an increase in large fire events, resulting in a doubling of annual burned area and more than a doubling of the frequency of larger fire years (>1,000 km2 or 620 mi2) (Kasischke and Turetsky 2006).

- Tundra fires generally accelerate carbon loss due to both direct burning and subsequent warming of soils causing higher rates of decomposition. One study found that for at least two decades following a tundra fire, the area was a carbon source, not sink (Oechel 1999).

- A tundra site was monitored post fire at intervals up to 24 years. There was little recovery of Sphagnum moss or fruticose lichens and shrub abundance increased (Racine et al. 2004).

- An increase in vascular plant cover, in particular shrub cover, was observed on several 20+ year old fire sites in Noatak National Preserve (Racine et al. 2006).

- Permafrost thickness did not return to its pre-fire thickness at several sites following a fire on the tundra (Racine et al. 2004).

- Insect outbreaks increase in frequency and severity with warmer temperatures (Juday et al. 2004).

- The majority of Alaskans polled anticipate that global climate change will cause increased flooding, worse storms, fewer salmon, and the extinction of the polar bear (Leiserowitz and Craciun 2006).

What scientists think is likely….

- In the decades following a major tundra fire on a hillslope in the Seward Peninsula, vegetation population shifts, major permafrost thawing, soil decomposition, and surface subsidence have been observed. These impacts suggest that similar fire events in other permafrost areas could result in similar impacts, which could even accelerate the predicted effects of climate warming (Racine et al. 2004).

- Research in Gates of the Arctic National Park and Preserve found that fire, in the short-term, may be an important tool in helping maintain yellow-cheeked vole populations; it creates new burrowing habitat and aids in the growth of forage (Swanson 1997).

- As sea ice diminishes, increasing commercial ship traffic through the Bering and Beaufort Seas and across the Northwest Passage will increase the risk, and potentially the environmental damage, from accidents, oil spills, and cargo spills (ACIA 2004).

- Due to ocean acidification, there has been a decrease in sound absorption. Based on current projections of future pH values for the oceans, a decrease in sound absorption of 40% is expected by mid-century (Hester et al. 2008).

What scientists think is possible….

- Ichthyophonus, a fish disease, infected 45% of Chinook salmon in the Yukon River and about 30% in the Tanana River between 1999 and 2003. Before 1985, Ichthyophonus was not reported affecting salmon in these rivers. Warmer water temperatures may have been contributed to the infections (Kocan et al. 2004).

- Model simulations suggest that a warming climate leads to slightly more fires and much larger fires, as well as expansion of forest into previously treeless tundra. Flammability increases rapidly in direct response to climate warming and more gradually in response to climate-induced vegetation change. The model predicts a 228% increase in the total area burned per decade (Dale et al. 2001; Rupp et al. 2000).

- Based on plant community type and fire trends, 11,000km2 (4,228 miles) or 25% of Yukon Flats National Wildlife Refuge located in the interior could burn by 2040. Between 2010 and 2080, approximately 70% of the refuge is predicted to experience new burns. Similar trends for other areas of the interior can be expected (Loya and Rupp 2009).

Models project slightly more fires and much larger fires in Alaska with a warmer climate; USFWS photo.

Subsistence hunting is subject to changes caused by climate shifts. Some game may become easier to hunt, and others may become harder to hunt using traditional practices (top). Children fishing at Kenai National Wildlife Refuge (bottom). USFWS photos.

CULTURAL RESOURCES

What scientists know....

- In western culture, changes in weather are considered to be an inconvenience, whereas expectations about its effects are absolutely integral to subsistence communities (Callaway 1999).

- A subsistence lifestyle is an integral component to a rural community and is not easily monetized. It provides more than nutrition and sustenance; it also provides spiritual values and community well being (Callaway 1999).

- Sea level rise, increased storm surges, and the impacts of permafrost erosion to infrastructure have begun to impact Native Alaskan communities, diverting resources from subsistence activities and in some cases requiring relocation of entire communities (Callaway 2007).

- Relocating indigenous communities represents a large financial cost for governments, but also impacts the communities themselves, potentially resulting in loss of integral cultural elements such as access to traditional use areas for subsistence activities, loss of history and sense of intact community, and potential loss of social networks and extended kin support (Callaway 2007).

- In Kotzebue, a mostly native community in northern Alaska, effects of climate change has been noticeable, but mixed. Changes in temperature, storm surges, and ice availability have led to easier whitefish and clam harvest, better spotted seal and caribou hunting by boat, easier access to arctic fox, and better access to driftwood. Conversely, these same changes have also meant a shorter ice fishing season, reduced access to and from Kotzebue for transfer of goods and services, increased erosion and flooding, and dangerous travel conditions associated with thawing or incomplete freezing of ice (Whiting 2002).

- Traditional subsistence practices are requiring more time and money than in the past, due to difficult hunting conditions associated with changes in climate patterns. This is putting a strain on subsistence communities, and in some cases can be a deterrent to engaging in traditional hunting at all (Berman and Kofinas 2004; Callaway 2007; Hanna 2007).

- According to the Alaska Department of Resources, Division of Lands, the winter tundra travel season on the Arctic North Slope has decreased from about 200 days in the 1970s to about 120 days in the early 2000s. Reliable travel over the frozen tundra enables natural resource development, access to subsistence sites, and travel between villages (Bradwell et al. 2004).

- The majority of Alaskans polled believe that global warming will seriously impact their families, communities, plants, and animals. Many believe that it will have serious impacts to Alaska within a decade (Leiserowitz and Craciun 2006).

What scientists think is likely....

- As glaciers and ice melt, cultural resources may be uncovered. Artifacts have been recovered from ice patches in Wrangell-St. Elias National Park. Five prehistoric sites were identified and contained artifacts ranging in age from 370 to 2880 radiocarbon years before present. Such artifacts can provide unprecedented glimpses into the lives of ancient people (Dixon et al. 2007).

- As sea ice conditions change, hunting for marine mammals is becoming more dangerous and costly. Marine mammals may follow sea ice retreat, altering their distribution and taking them out of range for some hunters (ACIA 2004; Callaway 1999).

A visitor hikes the Alaska Coastal Plain; USFWS photo.

- Subsistence communities have expressed concerns about increased pollution and its potential effects on the natural environment's ability to respond to climate change. Heavy metals and other contaminants bio-accumulate up the food chain. There are concerns that marine mammals, among other animals harvested for subsistence, could be sources of contaminants for hunters and their families as changes in circulatory patterns of water and air bring contaminants into the natural system (Callaway 1999). Researchers have found contaminants and heavy metals in the animals harvested for subsistence in the Arctic (Cooper et al. 2000; Dehn et al. 2006).

What scientists think is possible....

- Climate change may affect people's ability to conduct subsistence harvests due to changes in wildlife distribution and availability. Subsistence harvesting activities are linked to the health of rural residents in several ways, including the physical exertion of a hunt that promotes mental and physical well being, the nutritional value of harvested food items compared to store-bought food, and the value of maintaining a traditional diet (Callaway 1999).

- Migration patterns of terrestrial animals are predicted to change as temperatures, precipitation patterns, and vegetation availability change. An alteration in migration patterns could make hunting more challenging (ACIA 2004, Callaway 1999).

- Modeling of several feedback loops that take place within the Arctic hydrologic system (including those centered around cloud cover, water vapor, surface air temperature, precipitation, sea ice, marine productivity, human well-being, and land cover) shows that in a seasonally ice-free Arctic Ocean model, the complexity of the system is greatly reduced, affecting the function of the feedback loops and resulting in a decrease in human well-being in all scenarios (Francis et al. 2009).

- Some indigenous people in northern Alaska are concerned that as polar bears have an increasingly difficult time accessing prey and finding appropriate shelter for reproduction and protection, they may be more likely to approach villages and encounter humans. (ACIA 2004).

VISITOR EXPERIENCE

What scientists know....

- Glaciers, a main tourist attraction in many parks, are disappearing (Adema et al. 2007; Dyurgerov and Meier 2000; Larsen et al. 2007a; Molnia 2007).

- With increasing temperatures and more snow-free days, the length of the potential summer tourist season is increasing (Alaska Climate Research Center 2009; Dye 2002).

What scientists think is likely....

- Locations of climatically ideal tourism conditions are likely to shift toward higher latitudes under projected change, and as a consequence spatial and temporal redistribution of tourism activities may occur. The effects of these changes will depend greatly on the flexibility demonstrated by institutions and tourists as they react to climate change (Amelung et al. 2007).

- With the Northwest Passage ice-free for summer travel, an increase in visitation to the Arctic via cruise ship is expected (ACIA 2004).

- Increase in coastal erosion along the Bering Sea and Arctic Ocean could erode coastlines, affecting travel and tourist destinations (Smith and Levasseur 2003).

What scientists think is possible....

- Damage to roads, buildings, and other infrastructure, is predicted as the climate changes, due largely to permafrost thawing (ACIA 2004; Smith and Levasseur 2003). Damage could add $3.6 to $6.1 billion (10% to 20%) to future costs for Alaska's public infrastructure from now to 2030 and $5.6 to $7.6 billion (10% to 12%) from now to 2080 (Larsen et al. 2007b).

- The majority of Alaskans polled believe that tourism will increase as a result of global climate change (Leiserowitz and Craciun 2006).

III. No Regrets Actions: How Individuals, Parks, Refuges, and Their Partners Can Do Their Part

Individuals, businesses, and agencies release carbon dioxide (CO_2), the principal greenhouse gas, through burning of fossil fuels for electricity, heating, transportation, food production, and other day-to-day activities. Increasing levels of atmospheric CO_2 have measurably increased global average temperatures, and are projected to cause further changes in global climate, with severe implications for vegetation, wildlife, oceans, water resources, and human populations. Emissions reduction – limiting production of CO_2 and other greenhouse gases - is an important step in addressing climate change. It is the responsibility of agencies and individuals to find ways to reduce greenhouse gas emissions and to educate about the causes and consequences of climate change, and ways in which we can reduce our impacts on natural resources. There are many simple actions that each of us can take to reduce our daily carbon emissions, some of which will even save money.

An interpretive brochure about climate change impacts to National Parks was created in 2006 and was distributed widely. This brochure was updated in 2008.

Agencies Can...

Improve sustainability and energy efficiency

- Use energy efficient products, such as ENERGY STAR® approved office equipment, appliances and light bulbs.
- Initiate an energy efficiency program to monitor energy use in buildings. Provide guidelines for reducing energy consumption.
- Convert to renewable energy sources such as solar or wind generated power.
- Specify "green" designs for construction of new or remodeled buildings.
- Include discussions of climate change in park Environmental Management System.
- Conduct an emissions inventory and set goals for CO_2 reduction.
- Provide alternative transportation options such as employee bicycles and shuttles for within-unit commuting.
- Provide hybrid electric or propane-fueled vehicles for official use, and impose fuel standards for park vehicles. Reduce the number and/or size of park vehicles and boats to maximize efficiency.
- Provide a shuttle service or another form of alternate transportation for visitor and employee travel to and within the unit.
- Provide incentives for use of alternative transportation methods.
- Use teleconferences and webinars or other forms of modern technology in place of travel to conferences and meetings.

Implement Management Actions

- Engage and enlist collaborator support (e.g., tribes, nearby agencies, private landholders) in climate change discussions, responses, and mitigation.
- Develop strategies and identify priorities for managing uncertainty surrounding climate change effects in parks and refuges.
- Build a strong partnership-based foundation for future conservation efforts.
- Identify strategic priorities for climate change efforts when working with partners.
- Incorporate anticipated climate change impacts, such as decreases in lake levels, rising sea levels, or changes in vegetation and wildlife, into management plans.
- Encourage research and scientific study in park units and refuges.
- Design long-term monitoring projects and management activities that do not rely

Park Service employees install solar panels at San Francisco Maritime National Historical Park (Top); At the National Mall, Park Service employees use clean-energy transportation to lead tours; NPS photos.

solely on fossil fuel-based transportation and infrastructure.

- Incorporate products and services that address climate change in the development of all interpretive and management plans.
- Take inventory of the facilities/boundaries/species within your park or refuge that may benefit from or be vulnerable to climate change mitigation or adaptation activities.
- Participate in gateway community sustainability efforts.
- Recognize the value of ecosystem services that an area can provide, and manage the area to sustain these services. Conservation is more cost-effective than restoration and helps maintain ecosystem integrity.
- Provide recycling options for solid waste and trash generated within the park.
- Anticipate potential landscape and sea-level changes when designing new or replacement facilities and infrastructure, including positioning new facilities to avoid or mitigate impact from sea level rise or permafrost thawing.
- Work with native communities to identify climate refugia as special places for sustaining traditional subsistence living.

Restore damaged landscapes

- Restoration efforts are important as a means for enhancing species' ability to cope with stresses and adapt to climatic and environmental changes. Through restoration of natural areas, we can lessen climate change impacts on species and their habitats. These efforts will help preserve biodiversity, natural resources, and recreational opportunities.
- Strategically focus restoration efforts, both in terms of the types of restoration undertaken and their national, regional, and local scale and focus, to help maximize resilience.
- Restore and conserve connectivity within habitats, protect and enhance instream flows for fish, and maintain and develop access corridors to climate change refugia.

Educate staff and the public

- Post climate change information in easily accessible locations such as on bulletin boards and websites.
- Provide training for park and refuge employees and partners on effects of climate change on resources, and on dissemination of climate change knowledge to the public.
- Support the development of region, park, or refuge-specific interpretive products on the impacts of climate change.
- Incorporate climate change research and information in interpretive and education outreach programming.
- Distribute up-to-date interpretive products (e.g., the National Park Service-wide Climate Change in National Parks brochure).
- Develop climate change presentations for local civic organizations, user and partner conferences, national meetings, etc.
- Incorporate climate change questions and answers into Junior Ranger programs.

"Humankind has not woven the web of life. We are but one thread within it. Whatever we do to the web, we do to ourselves. All things are bound together. All things connect."
—Chief Seattle

- Help visitors make the connection between reducing greenhouse gas emissions and resource stewardship.
- Encourage visitors to use public or non-motorized transportation to and around parks.
- Encourage visitors to reduce their carbon footprint in their daily lives and as part of their tourism experience.

Individuals can...

- In the park or refuge park their car and walk or bike. Use shuttles where available. Recycle and use refillable water bottles. Stay on marked trails to help further ecosystem restoration efforts.
- At home, walk, carpool, bike or use public transportation if possible. A full bus equates to 40 fewer cars on the road. When driving, use a fuel-efficient vehicle.
- Do not let cars idle - letting a car idle for just 20 seconds burns more gasoline than turning it off and on again.
- Replace incandescent bulbs in the five most frequently used light fixtures in the home with bulbs that have the ENERGY STAR® rating. If every household in the U.S. takes this one simple action we will prevent greenhouse gas emissions equivalent to the emissions from nearly 10 million cars, in addition to saving money on energy costs.

Reduce, Reuse, Recycle, Refuse

- Use products made from recycled paper, plastics and aluminum - these use 55-95% less energy than products made from scratch.
- Purchase a travel coffee mug and a reusable water bottle to reduce use of disposable products (Starbucks uses more than 1 billion paper cups a year).
- Carry reusable bags instead of using paper or plastic bags.
- Recycle drink containers, paper, newspapers, electronics, and other materials. Bring recyclables home for proper disposal when recycle bins are not available. Rather than taking old furniture and clothes to the dump, consider "recycling" them at a thrift store.
- Keep an energy efficient home. Purchase ENERGY STAR® appliances, properly insulate windows, doors and attics, and lower the thermostat in the winter and raise it in the summer (even 1-2 degrees makes a big difference). Switch to green power generated from renewable energy sources such as wind, solar, or geothermal.
- Buy local goods and services that minimize emissions associated with transportation.
- Encourage others to participate in the actions listed above.

For more information on how you can reduce carbon emissions and engage in climate-friendly activities, check out these websites:

EPA- What you can do: http://www.epa.gov/climatechange/wycd/index.html

NPS- Do Your Part! Program: http://www.nps.gov/climatefriendlyparks/doyourpart.html

US Forest Service Climate Change Program: http://www.fs.fed.us/climatechange/

United States Global Change Research Program: http://www.globalchange.gov/

U.S. Fish and Wildlife Service Climate change: http://www.fws.gov/home/climatechange/

The Climate Friendly Parks Program is a joint partnership between the U.S. Environmental Protection Agency and the National Park Service. Climate Friendly Parks from around the country are leading the way in the effort to protect our parks' natural and cultural resources and ensure their preservation for future generations; NPS image.

CLIMATE *Friendly* PARKS

IV. Global Climate Change

The IPCC is a scientific intergovernmental, international body established by the World Meteorological Organization (WMO) and by the United Nations Environment Programme (UNEP). The information the IPCC provides in its reports is based on scientific evidence and reflects existing consensus viewpoints within the scientific community. The comprehensiveness of the scientific content is achieved through contributions from experts in all regions of the world and all relevant disciplines including, where appropriately documented, industry literature and traditional practices, and a two stage review process by experts and governments.

Definition of climate change: The IPCC defines climate change as a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. All statements in this section are synthesized from the IPCC report unless otherwise noted.

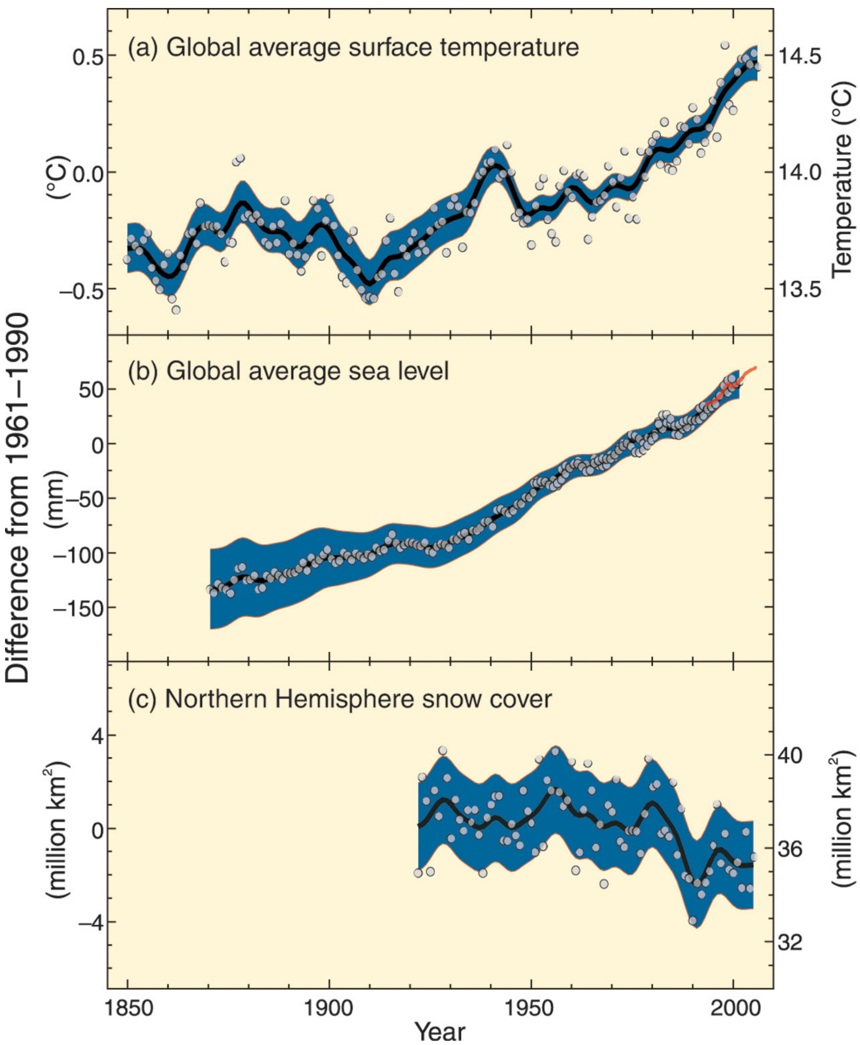


Figure 1. Observed changes in (a) global average surface temperature; (b) global average sea level from tide gauge (blue) and satellite (red) data and (c) Northern Hemisphere snow cover for March-April. All differences are relative to corresponding averages for the period 1961-1990. Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c) (IPCC 2007a).

A. Temperature and Greenhouse Gases

What scientists know…

- Warming of the Earth's climate system is unequivocal, as evidenced from increased air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level (Figure 1).

- In the last 100 years, global average surface temperature has risen about 0.74°C over the previous 100-year period, and the rate of warming has doubled from the previous century. Eleven of the 12 warmest years in the instrumental record of global surface temperature since 1850 have occurred since 1995 (Figure 1).

- Although most regions over the globe have experienced warming, there are regional variations: land regions have warmed faster than oceans and high northern latitudes have warmed faster than the tropics. Average Arctic temperatures have increased at almost twice the global rate in the past 100 years, primarily because loss of snow and ice results in a positive feedback via increased absorption of sunlight by ocean waters (Figure 2).

- Over the past 50 years widespread changes in extreme temperatures have been observed, including a decrease in cold days and nights and an increase in the frequency of hot days, hot nights, and heat waves.

- Winter temperatures are increasing more rapidly than summer temperatures, particularly in the northern hemisphere, and

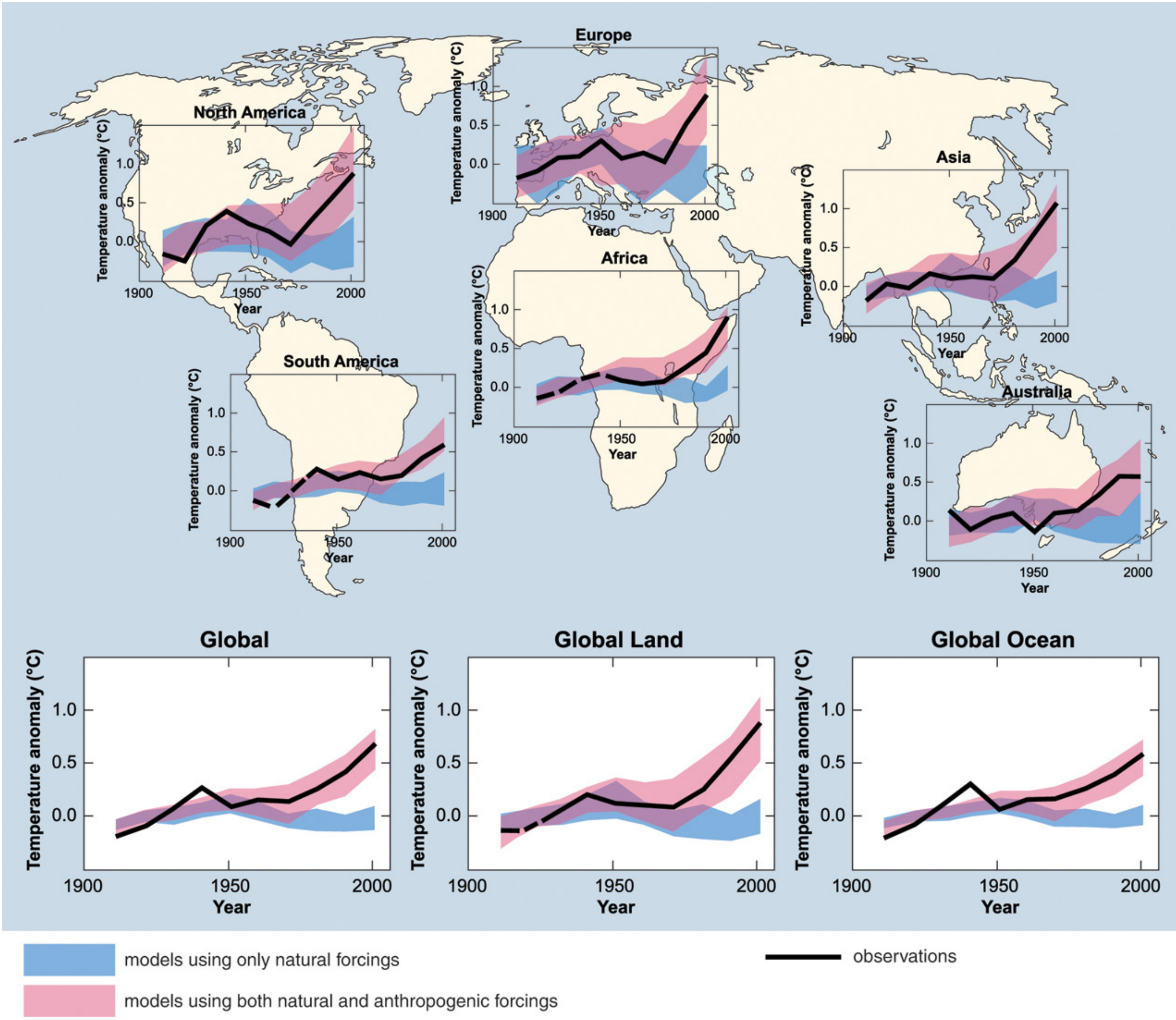


Figure 2. Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using either natural or both natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906-2005 (black line) plotted against the centre of the decade and relative to the corresponding average for the period 1901-1950. Lines are dashed where spatial coverage is less than 50%. Blue shaded bands show the 5 to 95% range for 19 simulations from five climate models using only the natural forcings due to solar activity and volcanoes. Red shaded bands show the 5 to 95% range for 58 simulations from 14 climate models using both natural and anthropogenic forcings (IPCC 2007a).

there has been an increase in the length of the frost-free period in mid- and high-latitude regions of both hemispheres.

- Climate change is caused by alterations in the energy balance within the atmosphere and at the Earth's surface. Factors that affect Earth's energy balance are the atmospheric concentrations of greenhouse gases and aerosols, land surface properties, and solar radiation.

- Global atmospheric concentrations of greenhouse gases have increased significantly since 1750 as the result of human activities. The principal greenhouse gases are carbon dioxide (CO_2), primarily from fossil fuel use and land-use change; methane (CH_4) and nitrous oxide (N_2O), primarily from agriculture; and halocarbons (a group of gases containing fluorine, chlorine or bromine), principally engineered chemicals that do not occur naturally.

- Direct measurements of gases trapped in ice cores demonstrate that current CO_2 and CH_4 concentrations far exceed the natural range over the last 650,000 years and have increased markedly (35% and 148% respectively), since the beginning of the industrial era in 1750.

- Both past and future anthropogenic CO_2 emissions will continue to contribute to warming and sea level rise for more than a millennium, due to the time scales required for the removal of the gas from the atmosphere.

- Warming temperatures reduce oceanic uptake of atmospheric CO_2, increasing the fraction of anthropogenic emissions remaining in the atmosphere. This positive carbon cycle feedback results in increasingly greater accumulation of atmospheric CO_2 and subsequently greater warming trends than would otherwise be present in the absence of a feedback relationship.

- There is very high confidence that the global average net effect of human activities since 1750 has been one of warming.

- Scientific evidence shows that major and widespread climate changes have occurred with startling speed. For example, roughly half the north Atlantic warming during the last 20,000 years was achieved in only a decade, and it was accompanied by significant climatic changes across most of the globe (NRC 2008).

What scientists think is likely…

- Anthropogenic warming over the last three decades has likely had a discernible influence at the global scale on observed changes in many physical and biological systems.

- Average temperatures in the Northern Hemisphere during the second half of the 20th century were very likely higher than during any other 50-year period in the last 500 years and likely the highest in at least the past 1300 years.

- Most of the warming that has occurred since the mid-20th century is very likely due to increases in anthropogenic greenhouse gas concentrations. Furthermore, it is extremely likely that global changes observed in the past 50 years can only be explained with external (anthropogenic) forcings (influences) (Figure 2).

- There is much evidence and scientific consensus that greenhouse gas emissions will continue to grow under current climate change mitigation policies and development practices. For the next two decades a warming of about 0.2ºC per decade is projected for a range of emissions scenarios; afterwards, temperature projections increasingly depend on specific emissions scenarios (Table 1).

- It is very likely that continued greenhouse gas emissions at or above the current rate will cause further warming and result in changes in the global climate system that will be larger than those observed during the 20th century.

- It is very likely that hot extremes, heat waves and heavy precipitation events will become more frequent. As with current trends, warming is expected to be greatest over land and at most high northern latitudes, and least over the Southern Ocean (near Antarctica) and the northern North Atlantic Ocean.

What scientists think is possible…

- Global temperatures are projected to increase in the future, and the magnitude of temperature change depends on specific emissions scenarios, and ranges from a 1.1ºC to 6.4ºC increase by 2100 (Table 1).

Table 1. Projected global average surface warming at the end of the 21st century, adapted from (IPCC 2007b).

Notes: a) Temperatures are assessed best estimates and likely uncertainty ranges from a hierarchy of models of varying complexity as well as observational constraints. b) Temperature changes are expressed as the difference from the period 1980-1999. To express the change relative to the period 1850-1899 add 0.5°C. c) Year 2000 constant composition is derived from Atmosphere-Ocean General Circulation Models (AOGCMs) only.

	Temperature Change (°C at 2090 – 2099 relative to 1980 – 1999)[a,b]	
Emissions Scenario	**Best Estimate**	**Likely Range**
Constant Year 2000 Concentrations[a]	0.6	0.3 – 0.9
B_1 Scenario	1.8	1.1 – 2.9
B_2 Scenario	2.4	1.4 – 3.8
A_1B Scenario	2.8	1.7 – 4.4
A_2 Scenario	3.4	2.0 – 5.4
A_1F_1 Scenario	4.0	2.4 – 6.4

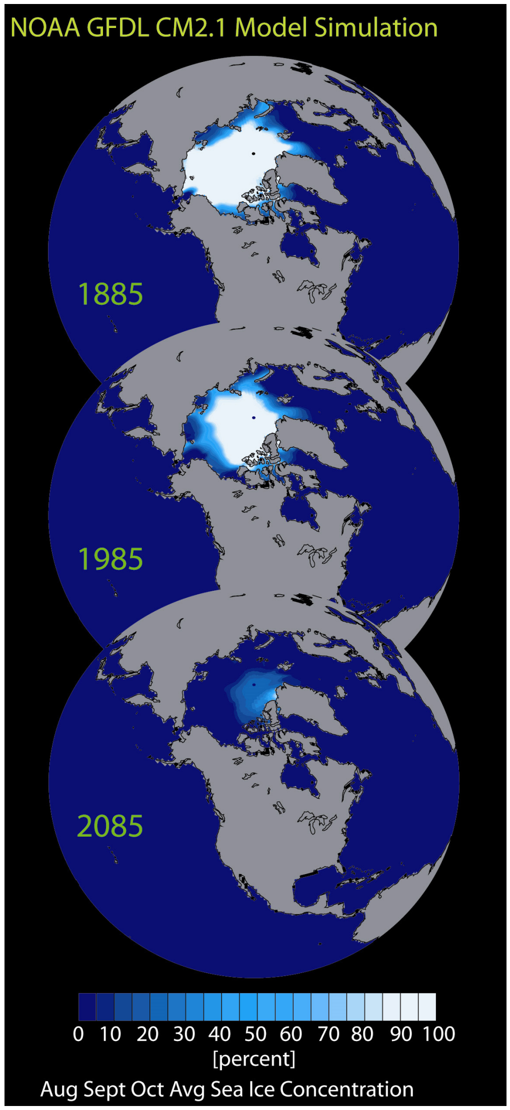


Figure 3. Sea ice concentrations (the amount of ice in a given area) simulated by the GFDL CM2.1 global coupled climate model averaged over August, September and October (the months when Arctic sea ice concentrations generally are at a minimum). Three years (1885, 1985 & 2085) are shown to illustrate the model-simulated trend. A dramatic reduction of summertime sea ice is projected, with the rate of decrease being greatest during the 21st century portion. The colors range from dark blue (ice free) to white (100% sea ice covered); Image courtesy of NOAA GFDL.

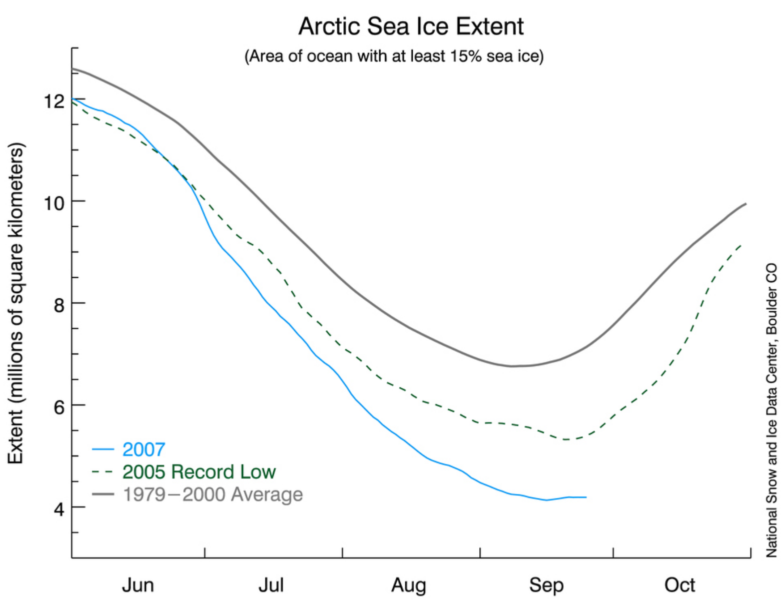


Figure 4. Arctic sea ice in September 2007 (blue line) is far below the previous low record year of 2005 (dashed line), and was 39% below where we would expect to be in an average year (solid gray line). Average September sea ice extent from 1979 to 2000 was 7.04 million square kilometers. The climatological minimum from 1979 to 2000 was 6.74 million square kilometers (NSIDC 2008).

- Anthropogenic warming could lead to changes in the global system that are abrupt and irreversible, depending on the rate and magnitude of climate change.

- Roughly 20-30% of species around the globe could become extinct if global average temperatures increase by 2 to 3°C over pre-industrial levels.

B. Water, Snow, and Ice

What scientists know…

- Many natural systems are already being affected by increased temperatures, particularly those related to snow, ice, and frozen ground. Examples are decreases in snow and ice extent, especially of mountain glaciers; enlargement and increased numbers of glacial lakes; decreased permafrost extent; increasing ground instability in permafrost regions and rock avalanches in mountain regions; and thinner sea ice and shorter freezing seasons of lake and river ice (Figure 3).

- Annual average Arctic sea ice extent has shrunk by 2.7% per decade since 1978, and the summer ice extent has decreased by 7.4% per decade. Sea ice extent during the 2007 melt season plummeted to the lowest levels since satellite measurements began in 1979, and at the end of the melt season September 2007 sea ice was 39% below the long-term (1979-2000) average (NSIDC 2008)(Figure 4).

- Global average sea level rose at an average rate of 1.8 mm per year from 1961 to 2003 and at an average rate of 3.1 mm per year from 1993 to 2003. Increases in sea level since 1993 are the result of the following contributions: thermal expansion, 57%; melting glaciers and ice caps, 28%, melting polar ice sheets, 15%.

- The CO_2 content of the oceans increased by 118 ± 19 Gt (1 Gt = 109 tons) between A.D. 1750 (the end of the pre-industrial period) and 1994 as the result of uptake of anthropogenic CO_2 emissions from the atmosphere, and continues to increase by about 2 Gt each year (Sabine et al. 2004; Hoegh-Guldberg et al. 2007). This increase in oceanic CO_2 has resulted in a 30% increase in acidity (a decrease in surface ocean pH by an average of 0.1 units), with observed and potential severe negative consequences for marine organisms and coral reef formations (Orr et al. 2005: McNeil and Matear 2007; Riebesell et al. 2009).

- Oceans are noisier due to ocean acidification reducing the ability of seawater to absorb low frequency sounds (noise from ship traffic and military activities). Low-frequency sound absorption has decreased over 10% in both the Pacific and Atlantic over the past 200 years. An assumed additional pH drop of 0.3 (due to anthropogenic CO_2 emissions) accompanied with warming will lead to sound absorption below 1 kHz being reduced by almost half of current values (Hester et. al. 2008).

- Even if greenhouse gas concentrations are stabilized at current levels thermal expansion of ocean waters (and resulting sea level rise) will continue for many centuries, due to the time required to transport heat into the deep ocean.

- Observations since 1961 show that the average global ocean temperature has increased to depths of at least 3000 meters, and that the ocean has been taking up over 80% of the heat added to the climate system.

- Hydrologic effects of climate change include increased runoff and earlier spring peak discharge in many glacier- and snow-fed rivers, and warming of lakes and rivers.

- Runoff is projected to increase by 10 to 40% by mid-century at higher latitudes and in some wet tropical areas, and to decrease by 10 to 30% over some dry regions at mid-latitudes and dry tropics. Areas in which runoff is projected to decline face a reduction in the value of the services provided by water resources.

- Precipitation increased significantly from 1900 to 2005 in eastern parts of North and South America, northern Europe, and northern and central Asia. Conversely, precipitation declined in the Sahel, the Mediterranean, southern Africa, and parts of southern Asia (Figure 5).

What scientists think is likely….

- Widespread mass losses from glaciers and reductions in snow cover are projected to accelerate throughout the 21st century, reducing water availability and changing seasonality of flow patterns.

- Model projections include contraction of snow cover area, widespread increases in depth to frost in permafrost areas, and Arctic and Antarctic sea ice shrinkage.

- The incidence of extreme high sea level has likely increased at a broad range of sites worldwide since 1975.

- Based on current model simulations it is very likely that the meridional overturning circulation (MOC) of the Atlantic Ocean will slow down during the 21st century; nevertheless regional temperatures are predicted to increase. Large-scale and persistent changes in the MOC may result in changes in marine ecosystem productivity,

Figure 5. Relative changes in precipitation (in percent) for the period 2090-2099, relative to 1980-1999. Values are multi-model averages based on the SRES A_1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change (IPCC 2007a).

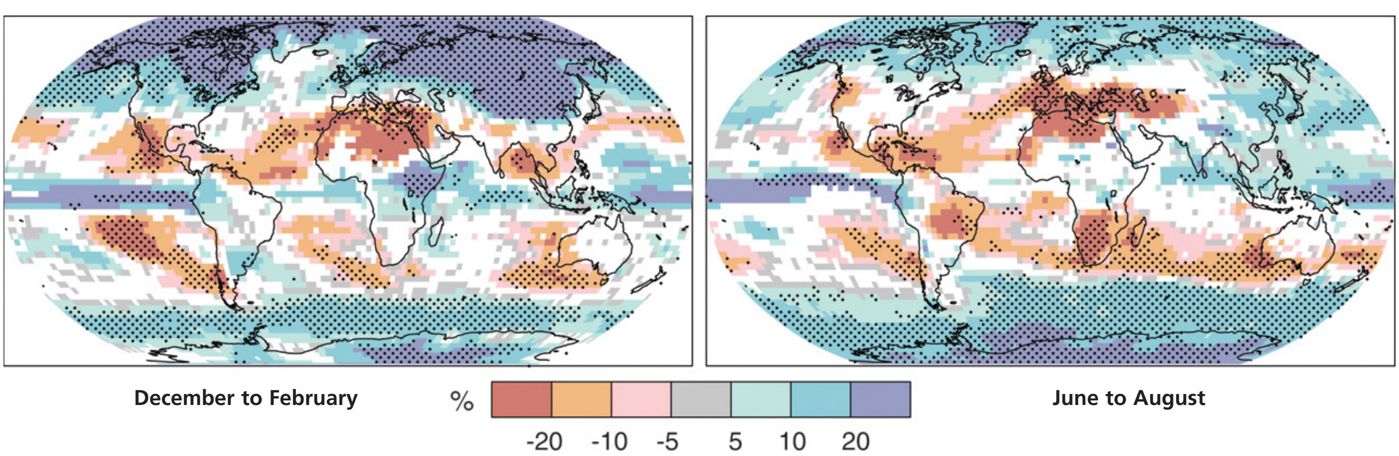


Table 2. Projected global average sea level rise at the end of the 21st century, adapted from IPCC 2007b.

Notes: a) Temperatures are assessed best estimates and likely uncertainty ranges from a hierarchy of models of varying complexity as well as observational constraints.

Emissions Scenario	Sea level rise (m at 2090 – 2099 relative to 1980 – 1999)
	Model-based range (excluding future rapid dynamical changes in ice flow)
Constant Year 2000 Concentrations[a]	0.3 – 0.9
B_1 Scenario	1.1 – 2.9
B_2 Scenario	1.4 – 3.8
A_1B Scenario	1.7 – 4.4
A_2 Scenario	2.0 – 5.4
A_1F_1 Scenario	2.4 – 6.4

fisheries, ocean CO_2 uptake, and terrestrial vegetation.

- Globally the area affected by drought has likely increased since the 1970s and the frequency of extreme precipitation events has increased over most areas.

- Future tropical cyclones (typhoons and hurricanes) are likely to become more intense, with larger peak wind speeds and increased heavy precipitation. Extra-tropical storm tracks are projected to move poleward, with consequent shifts in wind, precipitation, and temperature patterns.

- Increases in the amount of precipitation are very likely in high latitudes and decreases are likely in most subtropical land regions, continuing observed patterns (Figure 5).

- Increases in the frequency of heavy precipitation events in the coming century are very likely, resulting in potential damage to crops and property, soil erosion, surface and groundwater contamination, and increased risk of human death and injury.

What scientists think is possible…

- Arctic late-summer sea ice may disappear almost entirely by the end of the 21st century (Figure 3).

- Current global model studies project that the Antarctic ice sheet will remain too cold for widespread surface melting and gain mass due to increased snowfall. However, net loss of ice mass could occur if dynamical ice discharge dominates the ice sheet mass balance.

- Model-based projections of global average sea level rise at the end of the 21st century range from 0.18 to 0.59 meters, depending on specific emissions scenarios (Table 2). These projections may actually underestimate future sea level rise because they do not include potential feedbacks or full effects of changes in ice sheet flow.

- Partial loss of ice sheets and/or the thermal expansion of seawater over very long time scales could result in meters of sea level rise, major changes in coastlines and inundation of low-lying areas, with greatest effects in river deltas and low-lying islands.

C. Vegetation and Wildlife

What scientists know…

- Temperature increases have affected Arctic and Antarctic ecosystems and predator species at high levels of the food web.

- Changes in water temperature, salinity, oxygen levels, circulation, and ice cover in marine and freshwater ecosystems have resulted in shifts in ranges and changes in algal, plankton, and fish abundance in high-latitude oceans; increases in algal and zooplankton abundance in high-latitude and high-altitude lakes; and range shifts and earlier fish migrations in rivers.

- High-latitude (cooler) ocean waters are currently acidified enough to start dissolving pteropods; open water marine snails which are one of the primary food sources of young salmon and mackerel (Fabry et al. 2008, Feely et al. 2008). In lower latitude (warmer) waters, by the end of this century Humboldt squid's metabolic rate will be reduced by 31% and activity levels by 45% due to reduced pH, leading to squid retreating at night to shallower waters to feed and replenish oxygen levels (Rosa and Seibel 2008).

- A meta-analysis of climate change effects on range boundaries in Northern Hemisphere species of birds, butterflies, and alpine herbs shows an average shift of 6.1 kilometers per decade northward (or 6.1 meters per decade upward), and a mean shift toward earlier onset of spring events (frog breeding, bird nesting, first flowering, tree budburst, and arrival of migrant butterflies and birds) of 2.3 days per decade (Parmesan and Yohe 2003).

- Poleward range shifts of individual species and expansions of warm-adapted communities have been documented on all continents and in most of the major oceans of the world (Parmesan 2006).

- Satellite observations since 1980 indicate a trend in many regions toward earlier greening of vegetation in the spring linked to longer thermal growing seasons resulting from recent warming.

- Over the past 50 years humans have changed ecosystems more rapidly and extensively than in any previous period of human history, primarily as the result of growing demands for food, fresh water, timber, fiber, and fuel. This has resulted in a substantial and largely irreversible loss of Earth's biodiversity

- Although the relationships have not been quantified, it is known that loss of intact ecosystems results in a reduction in ecosystem services (clean water, carbon sequestration, waste decomposition, crop pollination, etc.).

What scientists think is likely…

- The resilience of many ecosystems is likely to be exceeded this century by an unprecedented combination of climate change, associated disturbance (flooding, drought, wildfire, insects, ocean acidification) and other global change drivers (land use change, pollution, habitat fragmentation, invasive species, resource over-exploitation) (Figure 6).

- Exceedance of ecosystem resilience may be characterized by threshold-type responses such as extinctions, disruption of ecological interactions, and major changes in ecosystem structure and disturbance regimes.

- Net carbon uptake by terrestrial ecosystems is likely to peak before mid-century and then weaken or reverse, amplifying climate changes. By 2100 the terrestrial biosphere is likely to become a carbon source.

- Increases in global average temperature above 1.5 to 2.5°C and concurrent atmospheric CO_2 concentrations are projected to result in major changes in ecosystem structure and function, species' ecological interactions, and species' geographical ranges. Negative consequences are projected for species biodiversity and ecosystem goods and services.

- Model projections for increased atmospheric CO_2 concentration and global temperatures significantly exceed values for at least the past 420,000 years, the period during which more extant marine organisms evolved. Under expected 21st century conditions it is likely that global warming and ocean acidification will compromise carbonate accretion, resulting in less diverse reef communities and failure of some existing carbonate reef structures. Climate changes will likely exacerbate local stresses from declining water quality and overexploitation of key species (Hoegh-Guldberg et al. 2007).

- Ecosystems likely to be significantly impacted by changing climatic conditions include:

  i. Terrestrial – tundra, boreal forest, and mountain regions (sensitivity to warming); Mediterranean-type ecosystems and tropical rainforests (decreased rainfall)

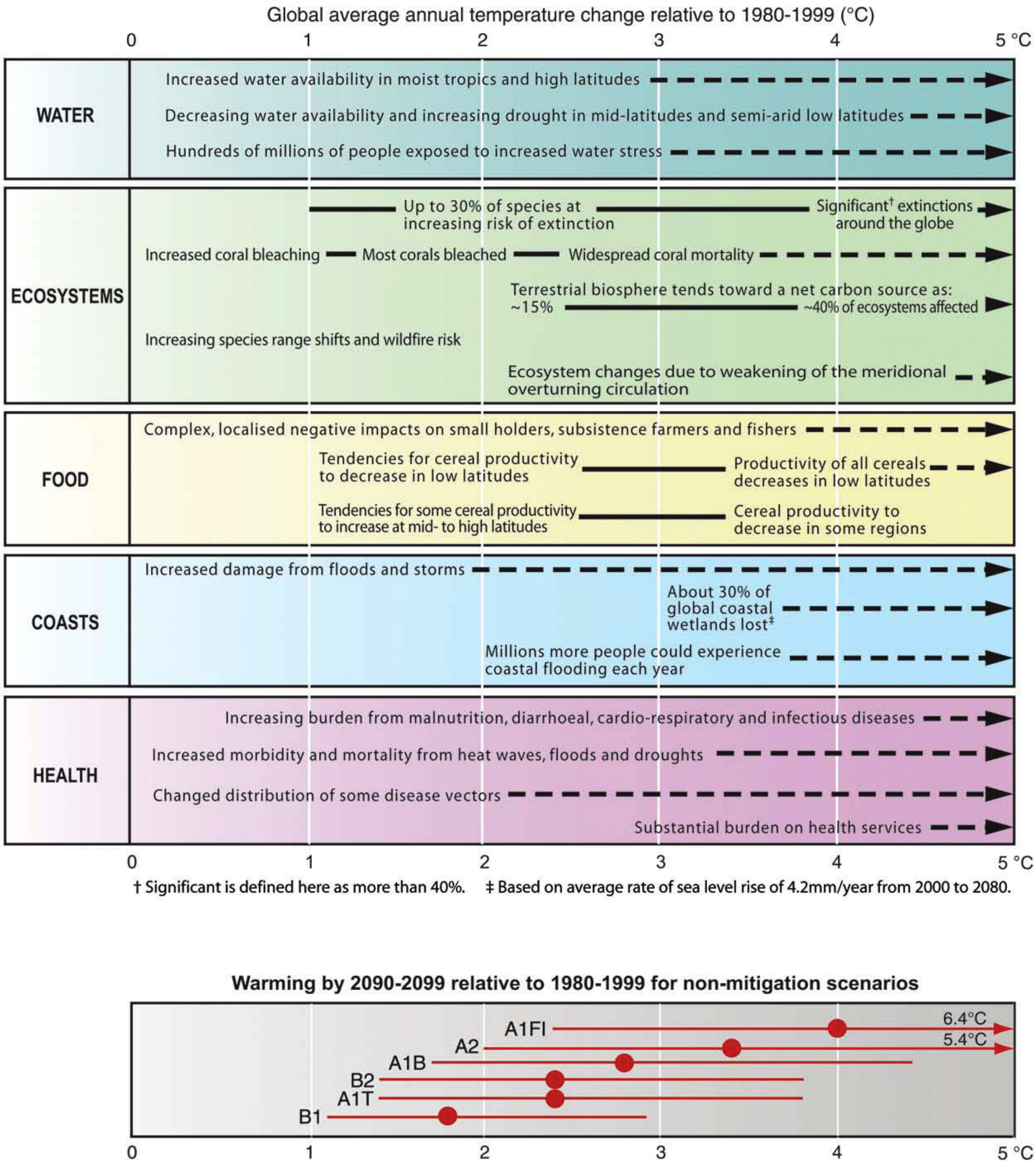


Figure 6. Examples of impacts associated with projected global average surface warming. Upper panel: Illustrative examples of global impacts projected for climate changes (and sea level and atmospheric CO_2 where relevant) associated with different amounts of increase in global average surface temperature in the 21st century. The black lines link impacts; broken-line arrows indicate impacts continuing with increasing temperature. Entries are placed so that the left-hand side of text indicates the approximate level of warming that is associated with the onset of a given impact. Quantitative entries for water scarcity and flooding represent the additional impacts of climate change relative to the conditions projected across the range of SRES scenarios A1FI, A2, B1 and B2. Adaptation to climate change is not included in these estimations. Confidence levels for all statements are high. Lower panel: Dots and bars indicate the best estimate and likely ranges of warming assessed for the six SRES marker scenarios for 2090-2099 relative to 1980-1999 (IPCC 2007a).

ii. Coastal – mangroves and salt marshes (multiple stresses)

iii. Marine – coral reefs (multiple stresses); sea-ice biomes (sensitivity to warming)

What scientists think is possible…

- Approximately 20% to 30% of plant and animal species assessed to date are at increased risk of extinction with increases in global average temperature in excess of 1.5 to 2.5°C.

- Endemic species may be more vulnerable to climate changes, and therefore at higher risk for extinction, because they may have evolved in locations where paleo-climatic conditions have been stable.

- Although there is great uncertainty about how forests will respond to changing climate and increasing levels of atmospheric CO_2, the factors that are most typically predicted to influence forests are increased fire, increased drought, and greater vulnerability to insects and disease (Brown 2008).

- If atmospheric CO_2 levels reach 450 ppm (projected to occur by 2030–2040 at the current emissions rates), reefs may experience rapid and terminal decline worldwide from multiple climate change-related direct and indirect effects including mass bleaching, ocean acidification, damage to shallow reef communities,reduction of biodiversity, and extinctions. (Veron et al. 2009). At atmospheric CO_2 levels of 560 ppmv, calcification of tropical corals is expected to decline by 30%, and loss of coral structure in areas of high erosion may outpace coral growth. With unabated CO_2 emissions, 70% of the presently known reef locations (including cold-water corals) will be in corrosive waters by the end of this century (Riebesell, et al. 2009).

D. Disturbance

What scientists know…

- Climate change currently contributes to the global burden of disease and premature death through exposure to extreme events and changes in water and air quality, food quality and quantity, ecosystems, agriculture, and economy (Parry et al. 2007).

- The most vulnerable industries, settlements, and societies are generally those in coastal and river flood plains, those whose economies are closely linked with climate-sensitive resources, and those in areas prone to extreme weather events.

- By 2080-2090 millions more people than today are projected to experience flooding due to sea level rise, especially those in the low-lying megadeltas of Asia and Africa and on small islands.

- Climate change affects the function and operation of existing water infrastructure and water management practices, aggravating the impacts of population growth, changing economic activity, land-use change, and urbanization.

What scientists think is likely…

- Up to 20% of the world's population will live in areas where river flood potential could increase by 2080-2090, with major consequences for human health, physical infrastructure, water quality, and resource availability.

- The health status of millions of people is projected to be affected by climate change, through increases in malnutrition; increased deaths, disease, and injury due to extreme weather events; increased burden of diarrheal diseases; increased cardio-respiratory disease due to higher concentrations of ground-level ozone in urban areas; and altered spatial distribution of vector-borne diseases.

- Risk of hunger is projected to increase at lower latitudes, especially in seasonally dry and tropical regions.

What scientists think is possible…

- Although many diseases are projected to increase in scope and incidence as the result of climate changes, lack of appropriate longitudinal data on climate change-related health impacts precludes definitive assessment.

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National Park Service
U.S. Department of the Interior

Natural Resource Program Center
1201 Oakridge Drive, Suite 200
Fort Collins, Colorado 80525

www.nature.nps.gov